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THE ROTATION AND RADIAL VELOCITY OF THE SPIRAL NEBULA N. G. C. 4594

By Francis G. Pease

MOUNT WILSON SOLAR OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

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The question of the rotation of nebulae has received a considerable amount of attention within recent years. The extreme faintness, however, of these objects, particularly of the spiral nebulae, makes spectroscopic investigation most difficult and laborious; and for only a very few of them are direct photographs available of such quality and separated by such intervals of time as to provide a reasonable hope of detecting changes of position by direct measurement.

In the case of the planetary nebulae Hartmann[1] in 1902 believed that he had found spectroscopic evidence of rotation in the large nebula in Draco and in Struve No. 6. His values, however, are not in accordance with the measures of Campbell and Moore, who recently have published definitive values for several of these nebulae.[2]

In his report for 1913 Wolf[3] stated that the lines in the spectrum of Messier 81, N. G. C. 3031 Ursae Majoris appeared doubly bent near the nucleus, indicating a rotation of 100 km. per sec. near the nucleus, the east side approaching. In *Lowell Observatory Bulletin*, No. 62, Slipher announced the rotation of the nebula which is the subject of this communication, and a few months later gave the numerical data referred to below. Later Wolf[4] mentions attempts to detect rotation in the Ring and Dumb-bell nebulae, but his apparatus was not well adapted to the work.

Van Maanen,[5] from measures of direct photographs, obtained evidence of rotation in Messier 101, together with a possible outward component for the individual knots, which seem to move along the arms of the spiral.

The great lengths of exposure necessary for spectrum work on faint nebulae has suggested the following modification of the slit end of the focal plane spectrograph so that several points in a nebula may be observed simultaneously. In this arrangement the metal jaws of the slit are replaced by a silvered glass plate. This plate and a direct photograph of the nebula taken at the same focus as that at which the spectrograph is to be used are mounted on a comparator, and for each bright spot in the nebula a slit (fig. 1) is cut in the silver film with a dividing attachment, the cut projecting beyond the nebulosity far enough to allow the addition of a comparison spectrum. Spots are chosen so that their spectra do not overlap. For the comparison spectrum another silvered glass plate is made in which for each continuous cut in the slit-plate there is an interrupted cut (fig. 2), the central portion covering the nebula while the comparison exposure is made on a spark between iron electrodes. This second plate is mounted on a metal frame which swings it almost into contact with the slit-plate when the spark is used. When not in use it is turned out of the way. A dense piece of opal glass between the spark and the slit serves to diffuse the light thoroughly. No projecting lens is employed. It is of course necessary in this arrangement to place the photographic plate at right angles to the axis of the camera.

At the Seventeenth Meeting of the American Astronomical Society, Slipher[6] gave for the nebula N. G. C. 4594 a radial velocity of + 1100 km. per sec., and stated that it has a rotation analogous to that of the planets. He assigns a value of 100 km. per sec. to the linear velocity of rotation at a distance of 20 seconds of arc from the nucleus.

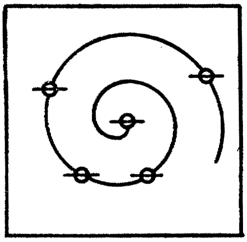

FIG. 1.

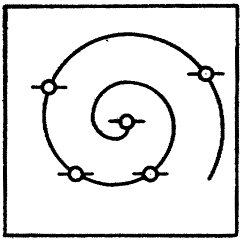

FIG. 2.

A direct photograph (fig. 3) of this nebula shows it to be a spiral seen almost edge on, with the convolutions so nearly concentric that it is not possible to state whether it is of the right or left-handed type. The nebula is crossed by a dark streak which appears to absorb or obstruct the light. This streak seems to lie at the periphery, being possibly an outer ring of cooler material, or perhaps the unilluminated edge of the thin disk of nebulous matter surrounding the brilliant nucleus. With possible differences of temperature in mind, a photograph was taken on a red sensitive plate through a color screen transmitting the region λ 5650–7600, to test for changes of contrast in visual and photographic light. No certain difference was found between this photograph and one taken upon a Seed '23' plate.

A spectrum exposure of 80 hours was made at intervals during March, April, and May, the slit being placed along the major axis of the spindle across the nucleus. Since the nebula is long and narrow a single straight line was in this instance cut in the slit-plate, while the spark plate was made in such a way that the nebular spectrum was traversed longitudinally by comparison spectra at intervals of 1 mm. The photographic plate accordingly was used in its regular position, and thus a large part of the spectrum was in focus.

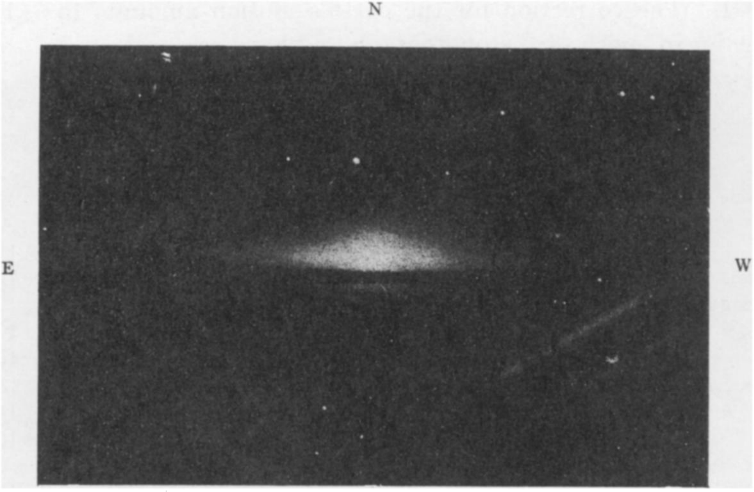

FIG. 3.—N. G. C. 4594 EXPOSURE = 2 HOURS. 1 MM = 6.7

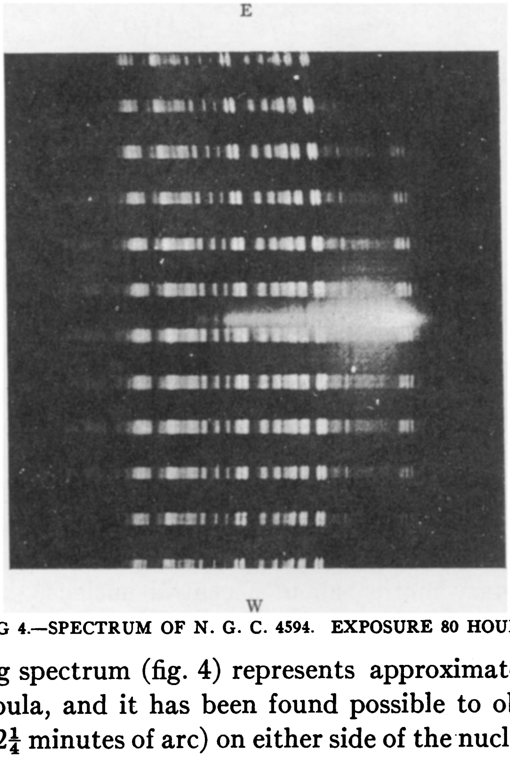

FIG 4.—SPECTRUM OF N. G. C. 4594. EXPOSURE 80 HOURS.

The resulting spectrum (fig. 4) represents approximately the central half of the nebula, and it has been found possible to obtain measures in five spaces ($2\frac{1}{4}$ minutes of arc) on either side of the nucleus. The type is about F5 and seems to be alike in all parts of this nebula. The linear scale of the spectrum is 4.3 mm. from λ 3930 to λ 4950 and most of the lines measured lie in the more refrangible portion of this region. A valuable check has been furnished by a photograph of the spectrum of the sky and spark taken in the same way as the nebular plate. The results of the measures by Mr. Adams and Miss Burwell are given in Table I. The correction for the earth's motion amounts to −1 km. for the mean epoch of the photograph and has been neglected.

		Adams		Burwell		Mean
		No. lines	Mean *km.*	No. lines	Mean *km.*	Velocity *km.*
West Side	5th space	2	+ 830	4	+ 775	+ 800
	4th space	4	960	6	905	930
	3rd space	4	980	6	930	955
	2d space	6	970	6	970	970
	1st space	6	1155	8	1105	1130
Nucleus		5	1210	7	1190	1200
Adjoining Nucleus		6	1250	7	1275	1260
East Side	1st space	7	1275	7	1275	1275
	2d space	7	1330	9	1350	1340
	3d space	5	1390	5	1395	1390
	4th space	4	+1380	4	1600	1490
	5th space			2	+1630	+1630

These velocities are shown in figure 5, the ordinates being kilometers per second and the abscissae seconds of arc. The velocity curve

$$y = -2.78x + 1180$$

was determined by a least squares solution. From this equation we find:

1. The radial velocity of the nebula is + 1180 km., a value in good agreement with that of + 1100 km. found by Slipher.

2. The linear velocity of rotation at a point 2 minutes of arc from the nucleus is over 330 km.

3. Within the limits of accuracy of the measures the change of rotational velocity is linear, although there may be some variation in individual parts of the nebula.

The third result may be interpreted either as indicating that the nebula is rotating as a solid body, or that the material is moving in accordance with a law which will give a linear velocity curve. The latter seems the more probable explanation, since the high velocity is opposed to our conceptions of stability in the case of a rotating solid body. In any event the results seem to be inconsistent with a system involving planetary motion about a central nucleus, since this would require an increase of linear velocity toward the center of the nebula.

If we assume that the rotational component of the internal motion in this nebula is of the same order as that found by van Maanen for Messier 101, we can at once derive a value for the parallax. Van

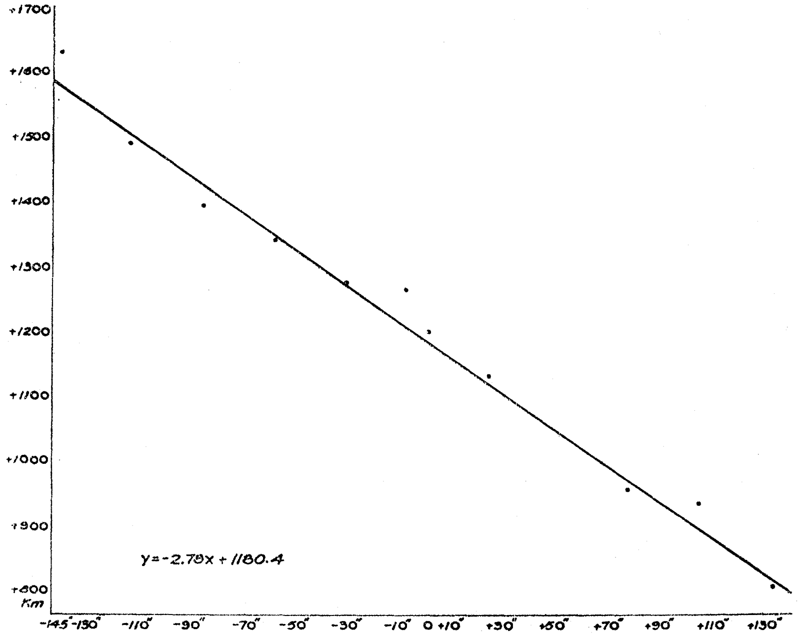

FIG. 5.

Maanen finds for Messier 101 an annual rotational component of $0''.022$ for a distance of 5′ from the center. Combining this with the rotational velocity of 330 km. per sec. for a distance of 2′ gives $0''.00013$ for the parallax of N. G. C. 4594. The result is of the same general order as that found by Curtis for spiral nebulae as a class from a discussion of their proper motion.[7]

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[1] *Astroph. J.*, 15, 287 (1902).

[2] *Lick Obs. Bull.*, 278 (1916); *Pub. Astr. Soc. Pac.*, 28, 119–20 (1916).

[3] *Leipzig, VierteljSchr. astr. Ges.*, 49, 162 (1914).

[4] *Ibid.*, 50, 97 (1915).

[5] Van Maanen, these PROCEEDINGS, 2, 386, July 1916.

[6] *Pop. Astr.*, 23, 21 (1915).

[7] *Pub. Astr. Soc. Pac.*, 27, 217 (1915).

A SIMPLE METHOD FOR DETERMINING THE COLORS OF THE STARS

By Frederick H. Seares

MOUNT WILSON SOLAR OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

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Aside from visual estimates, such as those by Müller and Kempf in the *Potsdam Durchmusterung*, three methods of determining the colors of stars have been more or less widely applied. The earliest of